THE SIGNIFICANCE OF THE MINIMUM DOPPLER DISPLACEMENT IN CANAL RAYS

B. V. SITAKUMARI

Patna Women's College, Patna

(*Received October* 21, 1963)

ABSTRACT. Measurements of the gap of zero intensity which exists between the undisplaced line of H_α, H_β and H_γ and the Doppler band in pure hydrogen are presented when the current in discharge tube is kept constant. The gap width rises as the accelerating voltage is increased. The width shows two small maxima at 3 kV and 6 kV which are interpreted as due to relatively large numbers of $H_4{}^+$ and $H_3{}^+$ ions respectively. These findings are in accord with earlier measurements of the intensity maxima observed in the Doppler band. The gap width maxima for H_α, H_β and H_γ do not lie at the same accelerating voltage because an increase in the voltage is thought to be associated with a decrease in the width of the ion energy distribution. Thus with increasing voltage, the gap width should increase more than linearly as has in fact been observed.

INTRODUCTION

When a potential difference $\geqslant 1kV$ is applied between the two electrodes of a canal ray tube, and the discharge tube, is filled with hydrogen at pressures of 10^{-2} to 10^{-3} mm of Hg with a cathode having a hole at its centre, a beam of positively charged and of neutral particles passess through the hole and finally enters a gas filled and field free space behind the cathode. The maximum kinetic energy of the positive ions in the canal rays is in general somewhat smaller than the equivalent voltage applied to the discharge tube. When the light emitted from canal rays is analysed by means of a spectrograph, the Doppler band, i.e. light at lower wavelength than the undisplaced Balmer lines of wavelength λ, is observed. The maximum wavelength of this band is given by $\frac{d\lambda}{\lambda} = v/c$ $\cos\theta$ where θ is the angle of observation with respect to the axis of the canal rays.

The width of the Doppler band can be up to 50 Å or more, depending upon the applied voltage. Fig. 1 shows schematically the light intensity as a function of wavelength, the undisplaced line and the Doppler band are separated by a region of nearly zero intensity—a gap of width $d\lambda_{min}$. Since these observations make use of a photographic plate, 'zero intensity' can be due to lack of measurable blackening or lack of numbers of the light emitting centres. The variation of the $\Delta\lambda_{max}$ with the applied voltage has been extensively studied. However the nature of the variation of the $d\lambda_{min}$ with V and the particles radiating in the region of lowest wavelength of the band have been investigated only in a few cases. In particular Sakuntala has studied the variation of the $d\lambda_{min}$ up to $8kV$ and found that $d\lambda_{min}$ increases with V and then approaches a constant

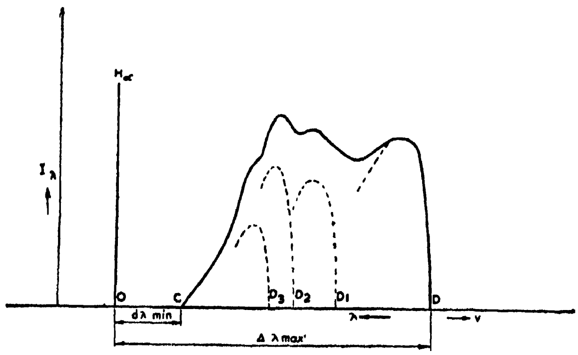

Fig. 1. Schematic diagram of a typical microphotometric trace of the Doppler band. I_λ, light intensity; H_α undisplaced line (6563Å); CD total width of the band; $d\lambda_{min}$ minimum wave length shift from the centre of the undisplaced line; $\Delta\lambda_{max}$ maximum wavelength shift; v beam velocity of excited atoms; D_1D...maximum speeds of H_α emitting atoms produced by H^+, H_2^+ etc. respectively.

value. The rise in gap width with voltage was thought to be due to the disappearance of H_4^+ ions. In this paper the variation of $d\lambda_{min}$ with V has been studied up to 16 kV in hydrogen for H_α, H_β and H_γ lines.

EXPERIMENTAL

A Steinheil three prism glass spectrograph of light gathering power $f/3$ and a tele-objective of focal length $f = 250$ cm, attached to the Camera, were used. The dispersion was 11.92 Å per mm for H_α and 4.3 Å per mm for H_β. With a Camera lens of $f = 640$ mm a dispersion of 16.5 Å per mm and 9.8 Å per mm was obtained for H_β and H_γ respectively. High purity of hydrogen was maintained by Wiens' method of capillary streaming and continuous pumping. The speed of flow of hydrogen was such that no appreciable pressure differences developed between the canal ray tube and the field free space behind the cathode. In this arrangement p, the gas pressure, could not be varied independently of V, thus V and p plotted on the same abscissa.

RESULTS

The results are shown in Fig. 2. It is seen that all the curves $d\lambda_{min} = f(V)$ have a similar trend. However the maximum at 3 kV does not appear as prominently as in Sakuntala's work (1953). Here $d\lambda_{min}$ rises with V and shows two small maxima at about 3kV and 6kV. It is interesting to note that Krefft (1924) observed for H_β that $d\lambda_{min}$ first increased with V but became constant between 3kV and 5 kV.

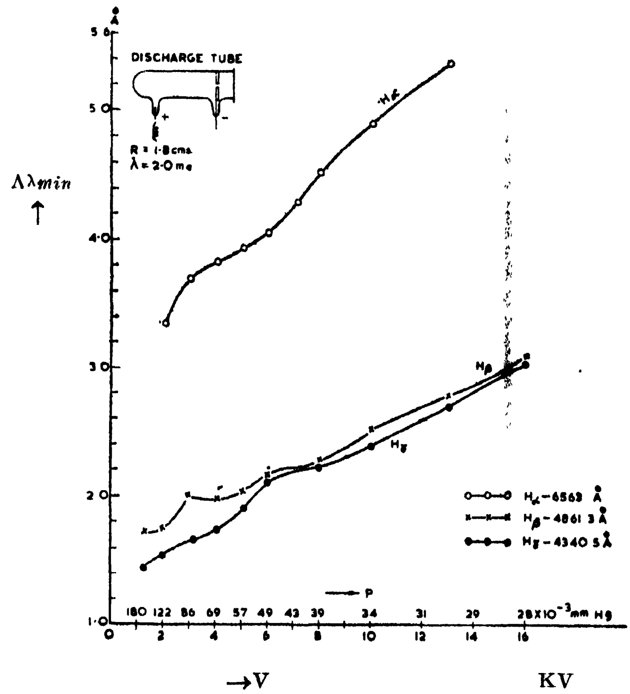

Fig. 2. Minimum wavelength shift $\Delta\lambda_{min}$ as a function of the discharge potential V.i = 2 ma; for each line t = 1 hour (exposure), H_α alone being taken with teleobjective.

The relative maxima for H_α, H_β and H_γ are found here to be at the different values of V. This may be due to the decrease in the width of the ion energy distribution at higher values of V as a result of which the light that originates from a particular type of ion may decrease more rapidly at larger λ the larger V.

DISCUSSION

Before discussing the processes which are responsible for the appearance and changes in the width of the gap, it is necessary to recall the findings concerning the origin of the light emission in Canal rays. W. Wien (1927) and his school made an extensive study of the emission processes and discovered charge transfer collisions early in 1900. It was concluded that the Doppler band arises from encounters between ions and gas molecules. They also found that the Canal ray light cannot be the result of an elastic collision and that it cannot be caused by electron ion recombination in stages. In spite of the fundamental importance this question has not been discussed for a long time.

Recently Sakuntala and von Engel (1960) suggested that the light in canal rays is the result of an inelastic collision. The fast ion in the canal ray hits a gas molecule or atom and forms a lived compound molecule which decays into several particles one of which is an electronically excited neutral particle which emits the light. Thus the collision results in a charge transfer associated with dissociation and excitation. From spectrographic data they were able to estimate the order of the cross section which they found to be between 10^{-19} and 10^{-20} cm^2.

As to the origin of the gap it is clear that its width corresponds to the smallest observable velocity of the radiating atoms. Since the radiating atoms acquire their velocity from the fast ions, it is to be expected that as the ion speed is increased the gap width should rise. Since $d\lambda_{min}$ should increase with V the centre of the ion distribution would move to higher speeds and therefore the slowest ions too would have larger speeds. This should be more so since the ion distribution becomes narrow at larger ion energy. The same argument should hold in the case when ions of different mass are present in the beam. Complications may arise, if ions of a certain type are more likely to be produced in the discharge than others.

The new mechanism indicated above explains earlier observations of the disappearance of the gap between the undisplaced line and the end of the Doppler band. For in the presence of impurities, such as organic molecules (oil), the fast ion can dissociate a hydrogenic substance and the kinetic energy of the ion would be shared by a large number of excited hydrogen atoms of low average speed. Owing to the distribution in energy and the angular scattering, light emitting centres down to zero kinetic energy are now present and the gap disappears.

The variation of the gap width with the voltage (Fig. 2) is therefore thought to be due to the charge transfer emission process, the change in the energy distribution of the ions present and changes in their relative abundance. We note first that $d\lambda_{min}$ rises with V in H_α, H_β and H_γ. This is in accordance with expectation as has been stated above. However two points require amplification. Firstly the gap $d\lambda_{min}$ was found to be finite and not zero as V approaches zero; this value seems to be higher for H_α than for H_β and H_γ. As the H_α line was studied with the teleobjective attachment the intensity in its case was much less than that of H_β or H_γ. It is suggested that this is caused also by the inertia of the photographic emulsion. The spectral sensitivity together with the threshold of the emulsion causes an apparently larger gap width for red line than for the blue line, a suggestion which would also explain the small difference between H_β and H_γ. For the photographic plate used (Kodak P1200) the relative photographic sensitivity for H_α, H_β and H_γ (the product of sensitivity of the emulsion the relative intensity of the black body radiation) is in the ratio 8 to 45 to 56 which supports the suggestion made. If the width of the ion energy distribution curves and the relative abundances would remain constant, $d\lambda_{min}$ would be expected to rise linearly with V, provided de-excitation processes are independent of V and p. In fact quenching can be ruled out because the deviation from the linearity in Fig. 2 occurs at larger V and hence smaller p.

The relative maxima observed in the three curves of Fig. 2, can be explained in the following way : when V is increased (and p reduced) the peaks of two successive ion energy distribution curves will increase and the width of the curves decrease. Hence $d\lambda_{min}$ will rise faster than linearly. If however, the relative abundance of ions of lower mass number increases faster than those of higher mass, the net result can be a slowing down of the increase in $d\lambda_{min}$ which means that a maximum in $d\lambda_{min}$ arises. It is seen that the maxima in H_α do not appear precisely at the same V as those of H_β and H_γ. Whether this is due to low photographic sensitivity in red or not is not certain.

The maxima in light emission in the Doppler band have been connected with H^+, H_2^+ etc. and so have their relative maxima in $d\lambda_{min}$. In particular the existence of a moderate number of H_4^+ ions has been suggested from the earlier measurements. However Dopel (1925) thought to have observed such species by mass spectroscopy. Recently new evidence has been supplied by measurements of ion species produced in glow discharge in H_2 and analysed with mass spectrometer. Dawson and Tickner found ions of mass 4 and 5. The mass 4 ion was interpreted as H_2D^+ but I think that not sufficient convincing data have been supplied not to interpret this species as a H_4^+ ion. The author suggests that the ion of mass 5 is H_5^+. Since a small relative maximum has been observed on the low wavelength side of the Doppler band when V is above 2kV, it is suggested that the first maximum in $d\lambda_{min}$ is associated with disappearance of H_4^+ ions whose existence still requires more evidence. The second maximum in $d\lambda_{min}$ is probably associated with H_3^+ which is found to exist even up to 16kV but decreases in abundance having a peak value at 6KV[3].

ACKNOWLEDGMENT

I am indebted to Dr. B. Dasannacharya, Retired Head of the department of Physics, Banaras Hindu University under whose guidance the above work was done by me for the Ph.D. Dissertation during the years 1953-1955. I am very thankful to Dr. M. Sakuntala, Physics Department, Banaras Hindu University, now in the Atomic Energy Research Establishment, Harwell, U. K. for the discussion and help she gave in the presentation of the matter. I have great pleasure in offering to Professor A. Von Engel of Oxford University my sincere thanks for his kind criticism and helpful suggestions.

REFERENCES

Dassanacharya, B. and Dakshinamurti, C., 1944 *Nature;* **154**, 22.
Dassanacharya, B. and Das, G. K., 1948, *Phil. Mag.* **39**, 966.
Dassanacharya, B. *Current Sci.*, Canal Rays special number pp. 10-19 Sept. 1937.
Dopel, R. 1925, *Ann. Phys.* L p. 376, **1**.
Dawson, P. H. and Tickner, A. W. 1962, *J. Chem. Phys.* **37**, 672.
Krefft, H. 1924, *Ann. d. Phys.*, **75**, 75.
Kodak Handbook on Photographic plates.
Strasser, B. 1920, *Ann. D. Phys.* **31**, 895.
Sitakumari, B. V. Doctorate Dissestation BHU, 1956.
Sakuntala, M. and Dassanacharya, B. 1953, *Curr. Sci.* **22**, 167.
Sakuntala, M. and von Engel, A. 1960, *Journal of Electronics and Control* **9**, 1, 31.
Wien, W., 1927, Handbook Exp. Phys. L p. 2 **14**.